THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 60, No. 6, July-August 1981
Printed in U.S.A.

No. 4 ESS:

Performance Objectives and Service Experience

By E. A. DAVIS and P. K. GILOTH

(Manuscript received July 16, 1980)

The development plan of the No. 4 ESS included provisions for measuring the effectiveness of the design, operation, maintenance, and administration of the total system. This paper reviews system performance from 1976 to 1980, describes principal factors affecting system performance, and presents the service experience measured for the No. 4 ESS. Steady improvement has been measured in the number of service-affecting incidents experienced per office each month. This improvement is also reflected in the rate of cutoff and denied calls, as well as in system "no call processing" time. We discuss some of the factors influencing this performance record, e.g., a sound initial design, reliable hardware, effective maintenance and repair tools, continuing analysis and resolution of causes of service-affecting incidents, and continuing development of new features for performance improvement.

I. INTRODUCTION

The No. 4 ESS is a digital time-division toll and tandem switching system first placed in service in Chicago. It was described in the *Bell System Technical Journal* in 1976.[1] Since then, 51 offices with over 1,000,000 terminations have been put into service. The deployment progress is shown in Fig. 1. The average size of the No. 4 ESS is 22,000 terminations with current office sizes ranging from 6,000 to over 60,000 terminations. Detailed statistics demonstrate that the No. 4 ESS provides high-quality service to its customers and that its performance continues to improve as the system matures despite office growth, new generic programs, and evolving hardware.

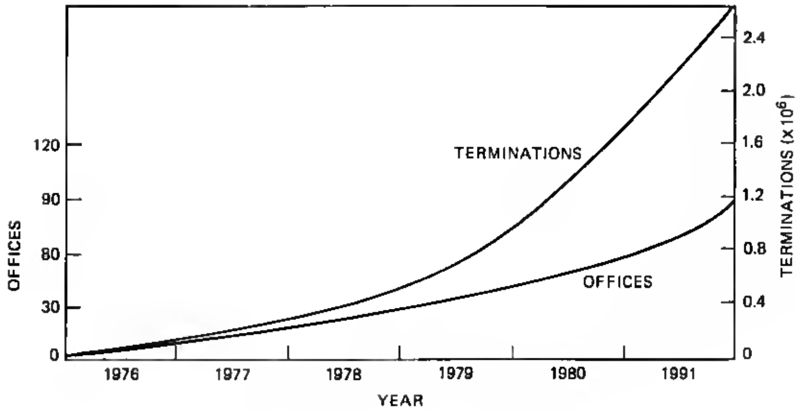

Fig. 1—No. 4 ESS deployment.

Substantial effort has been applied to developing methods and procedures for evaluating the performance of hardware and software in the No. 4 ESS. Data collection on performance parameters was built into the initial design so that performance data from many No. 4 ESS systems could be obtained easily and accurately. New performance criteria have been developed to measure the effect on the customer and to provide data for maintaining the hardware and software.

A typical No. 4 ESS has intertoll and toll connecting trunks to about 200 other switching entities. Therefore, because of its size and position in the network, its continuous availability for service is needed since any malfunction can affect communication in many areas of the country. All No. 4 ESS machines are staffed 24 hours a day, 7 days a week, and all service-affecting incidents are reported and analyzed. Special attention is given to correct the causes of service-affecting incidents.

This paper describes some of the major system objectives, specific reliability and maintainability objectives, operational factors affecting performance, service experience, and methods used to manage performance. References 1 through 8 provide additional information on system performance.

II. SYSTEM OBJECTIVES

The traditional measure of telephone switching system reliability and performance is the amount of "no call processing" time in 40 system years. This measure is a useful design objective, but it does not include all of the effects of complete and partial system failures which can lead to unsatisfactory performance from a customer viewpoint.

The primary objective is to minimize the impact on the customer of

all types of system failures. Consequently, cutoff calls and denied calls are among the most important performance indicators measured in the No. 4 ESS. Many other performance indicators are also measured to determine the effectiveness of maintenance and operation so that procedures and design problems can be corrected promptly.

As an example, the derivation of the cutoff call objective for a toll call is shown in Fig. 2. Calls are assumed to pass through two local offices, two toll offices, and interconnecting transmission facilities. As shown, the overall call cutoff objective is less than or equal to 15 calls per 10,000, with an allocation to each switching entity of less than or equal to 1.25 calls per 10,000.

Special performance criteria were set for the cutover of the first No. 4 ESS in Chicago in 1976 (referred to as Chicago 7). They were expressed both as objectives and concern thresholds.[1] Table I lists the objectives.

Performance objectives have also been set for other performance indicators where supporting information is available. However, some performance measures are new, and the present, self-imposed, objectives are based on data obtained from typical No. 4 ESS offices and were not part of the original design objectives. The new objectives are described later in this paper.

The design of reliable telephone switching systems involves built-in tools to measure performance, as well as reliable hardware, software, and equipment configurations. Objectives must be set that are stringent, yet attainable at a reasonable cost. Objectives for the No. 4 ESS performance are based on a reliability model and field data from the existing network. Advances in technology and the expectations of the public are also considered in setting objectives.

The ultimate performance of telephone switching systems depends on design, as well as installation, operation, and maintenance. Conse-

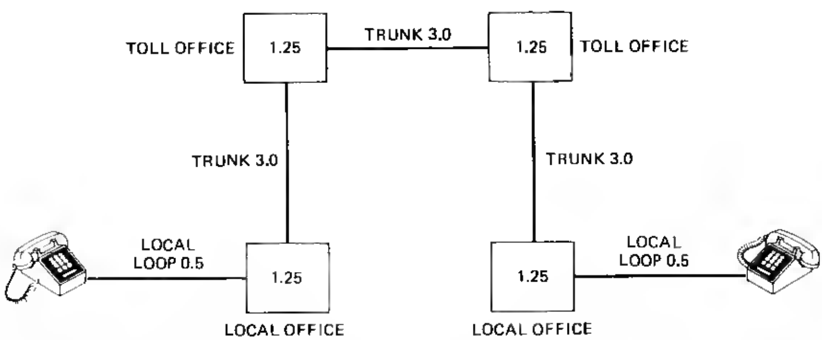

Fig. 2—Allocation of cutoff calls objective in calls per 10,000. The total cutoff call objective is less than or equal to 15 calls per 10,000.

Table I—Chicago 7 cutover objectives

Description	Objectives
Ineffective Attempts	<1.25 percent
Plug-in Replacements	<2 per day
Interrupts	<50 per day
Phases (2 or higher)	<1/2 per month

quently, standards have been developed for final installation acceptance tests, daily equipment performance, and routine maintenance procedures.

III. RELIABILITY AND MAINTAINABILITY OBJECTIVES

A primary architectural feature of the No. 4 ESS is the system organization and design which provides dependable hardware and a software structure that can be operated and maintained by craft personnel. These objectives have been accomplished by using reliable circuitry and hardware redundancy with extensive supporting software.

The software design provides centralized maintenance control from the 1A Processor. The processor and the peripheral equipment have configurable redundancy, which is accomplished automatically without affecting service. An automatic backup for the processor semiconductor memory is provided by the disk system, which in turn has a magnetic tape system backup. A detailed description of circuit reliability and system redundancy can be found in Ref. 2.

3.1 Reliability

The basic element of a reliable system is well-designed hardware tbat includes trouble-detection features and ease of component replacement. The development of the No. 4 ESS is based on a gold metal system for semiconductors and their interconnection. The connector contacts are also gold plated. The basic design features include open-frame convection cooling (rather than fan cooling) and the ability to operate in a temperature range of 30°F to 120°F. Tbe hardware is designed to make per-frame checks and depends on a centralized software maintenance system to automatically reconfigure the hardware in case of trouble, to diagnose the frame reporting irregularities, and to locate the faulty component so it can be replaced by maintenance personnel.

A reliability model was developed for the No. 4 ESS to help translate service objectives into a redundancy plan and to predict long-term performance. The No. 4 ESS reliability model specifies a number of hardware failure modes, determines their impact on performance, and

predicts their likelihood of occurrence.[2] The model was derived principally through analysis of predicted hardware failure rates, system hardware configurations, and predicted repair times. However, the model did not attempt to directly account for the following factors:

(*i*) procedural errors,
(*ii*) change activity,
(*iii*) growth,
(*iv*) retrofits,
(*v*) routine exercise,
(*vi*) software deficiencies, and
(*vii*) hardware design deficiencies.

Instead, the hardware failure rates predicted by the model were scaled to account for procedural errors and software errors based on experience gained from previous systems. No provision was made for generic program retrofits since their frequency is determined by the rate of new feature introduction in each office, which was unknown at that time.

The hardware reliability of the overall system is a function of its size, hardware failure rates, redundancy plan, and mean repair times. Data taken over a 4-year period show that the predicted hardware failure rates essentially bave been met. Special repair studies have been conducted which show that the mean time to repair solid faults is 1.25 hours while the mean time to repair intermittent faults is 20.5 hours. As shown in Fig. 8, component failures cause only 11 percent of the service-affecting incidents.

3.2 Maintainability

The No. 4 ESS is designed to perform extensive maintenance functions automatically so that, problems are rapidly corrected and personnel costs are minimized. The initial design provided work centers at each office for maintenance and administration. Experience has shown that centralized maintenance and administration for up to six No. 4 ESSs is possible.

Switching Management Control Centers (SMCCs) have been implemented to centralize the maintenance functions. This has led to the centralization of expertise, reduction of total maintenance personnel, and improved system performance. Additional centralization of Machine Administration Centers and Trunk Operations Centers is planned for the future.[3]

Current field experience demonstrates that the basic system design is highly reliable and that craft-level personnel can maintain the system. Hardware displays, software support tools, and new maintenance documentation (task-oriented practices) have contributed significantly to the performance of the maintenance personnel.

IV. OPERATIONAL FACTORS AFFECTING PERFORMANCE

The principal operational factors affecting performance of a No. 4 ESS are the change and repair activities and some of the environmental factors that can affect No. 4 ESS service. Taken together, they represent a high level of activity in many offices. Section V presents performance statistics which include the service impact of these activities.

4.1 Variety of system configurations

One significant factor is the variety of configurations of the No. 4 ESS. Each installation is engineered to match the service requirements of a particular location; therefore, each office is different. This implies that fault recognition and system recovery programs must be able to operate with any of the possible equipment configurations.

4.2 Evolution of equipment

As mentioned earlier, the equipment comprising the No. 4 ESS has evolved rapidly and many early offices have added each new type of equipment as it became available. The result is a mixture of vintages of equipment, complicating the environment in which system integrity and fault recognition programs must operate. An example is the first No. 4 ESS office, Chicago 7. It has a mixture of core, small (64K) semiconductor and large (256K) semiconductor memory frames. Similarly, in its time-division network, Chicago 7 has original vintage Time Slot Interchange (TSI) frames, a cost-reduced vintage of TSI frames, and the present version called the TSI-B.

Virtually every type of equipment has evolved to incorporate new technology since initial introduction: the Digroup Terminal (DT) has been cost reduced and replaced with the Digital Interface Frame (DIF), the Signal Processor was replaced with the Signal Processor 2 and eventually its signal processing function was incorporated into the DIF, Common-Channel Interoffice Signaling (CCIS) terminals have been improved, and the common control echo suppressor was added and will be superceded by per-trunk echo cancelers. Figure 3 gives a more complete picture of the evolution of No. 4 ESS equipment.

4.3 Growth activity

The rate of growth additions to existing No. 4 ESS systems has increased steadily. Figure 4 shows the number of major growth jobs in progress and the number of new No. 4 ESS offices placed in service during each year since 1976. Nearly two-thirds of the operational No. 4 ESS systems have been expanded with growth jobs. Through the end of 1979, growth activity had added over 900 frames of ESS equipment and provided over 350,000 new terminations, or nearly one-third of all installed No. 4 ESS terminations. Several offices have been expanded

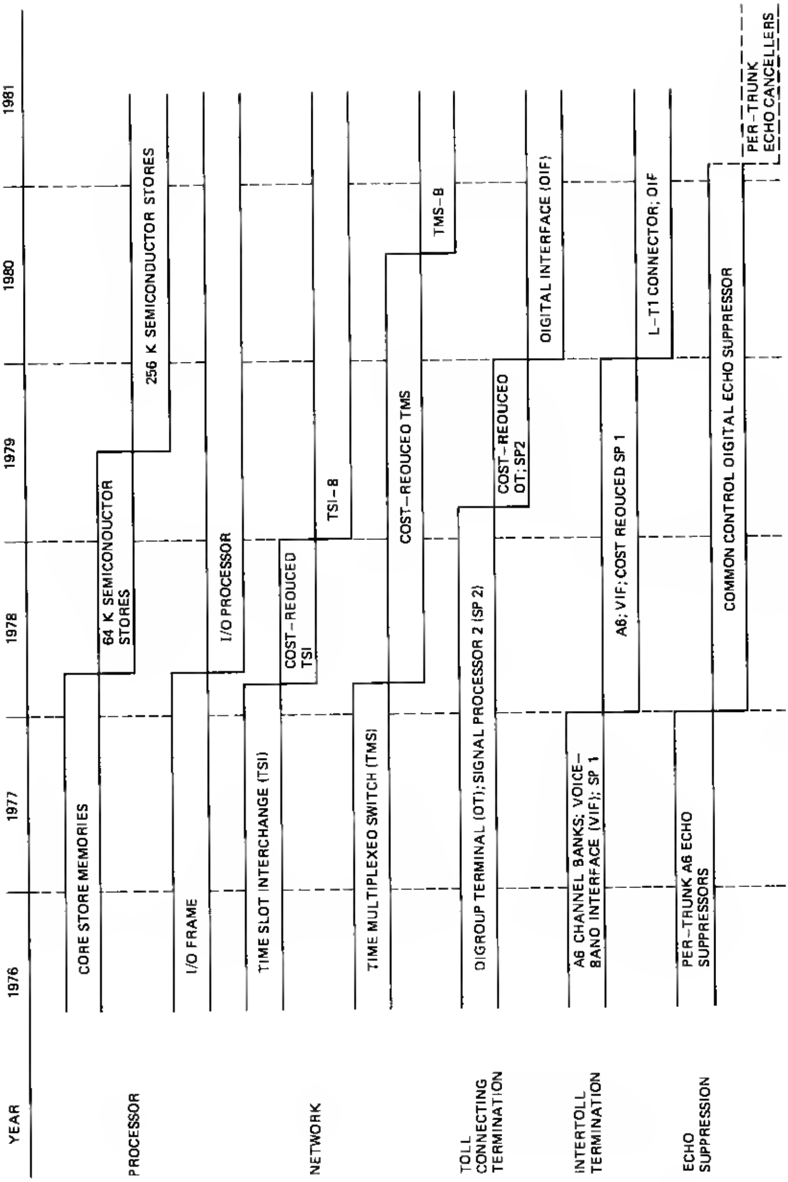

Fig. 3—Evolution of No. 4 ESS equipment.

several times, sometimes with additions providing 30,000 terminations.[4]

The growth process has been designed so equipment can be added without affecting service. However, growth and related activities have been responsible for approximately 5 percent of the service-affecting incidents (see Section 5.2) in the No. 4 ESS. The principal causes of

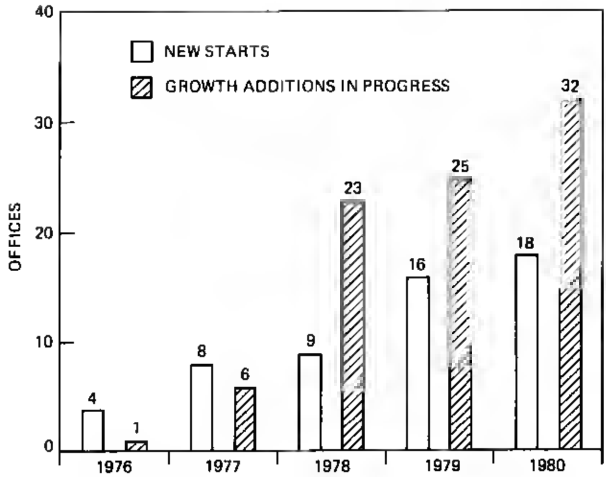

Fig. 4—Trend in No. 4 ESS growth activity.

these incidents have been human error, system software problems, and equipment failure in some of the new equipment shortly after it was made operational. Some of the improvements made in the growth process have been to incorporate temperature stress tests and extra network transmission path checks into selected growth procedures to improve the reliability of the new equipment once it is made operational.

4.4 Hardware change activity

Over 400 Change Notices (CNs) have been prepared by Western Electric to implement hardware changes in No. 4 ESS equipment. The scope of CNs includes wiring changes, circuit pack changes (including firmware updates), documentation, and addition of new types of equipment to existing frames. CNs may be stimulated by design changes initiated by Bell Laboratories or by the discovery of manufacturability problems discovered by Western Electric. All hardware changes are authorized and monitored by the No. 4 ESS hardware change committee. The Western Electric Product Engineering Control Center (PECC) tracks application of CNs in the field.

4.5 Software change activity

Software problems account for 25 percent of all No. 4 ESS service-affecting incidents. These are problems not detected in laboratory system tests or in first application office field tests. Such problems may go undetected until the generic program is introduced into an office with a particular configuration. Some software problems are

caused by incomplete defensive checks and are only stimulated through combinations of failures; others are simply design errors.

Table II shows the size of the No. 4 ESS program with the introduction of each new version. The numbers of problems corrected after the generic was placed in service are also shown. Although the quality of each generic issue is improving, as demonstrated by the decreasing number of service affecting incidents per office (Fig. 7), the number of field problems fixed has increased for each generic. This is a result of greater exposure to different office configurations and the contribution of undiscovered problems carried forward from previous generics. Generally, these software changes are of two types: the relatively few urgent fixes are called out to all offices or transmitted by the Software Change Administration and Notification System and installed with generic utility overwrites; the remainder are installed only when a partial update is distributed to each office. A partial update is a technique for introducing large numbers of program corrections without affecting service. Figure 5 shows a plot of the problems identified, fixes under test, and overwrites delivered to the field for the 4E4 generic.

One of the major reasons the No. 4 ESS has provided excellent service, despite the existence of software problems, is its basic system architecture and software integrity design. It is not technically or economically feasible to detect and fix all software problems in a system as large as the No. 4 ESS. Consequently, a strong emphasis has been placed on making it sufficiently tolerant of software errors to provide successful operation and fault recovery in an environment containing software problems.

Another type of software change activity involves the office data base which includes translations, parameters, trunking, and routing information. Occasionally, corrections and changes are made to the office data base with standard recent change methods and also with generic utility system overwrites.

4.6 Retrofits

A major type of software change activity is a generic retrofit in

Table II—Field problems

Generic	Service Date	Total Size (words)	No. of Field Problems Fixed
4E0	1/76	1160*K*	—
4E1	7/76	1312	249
4E2	6/77	1405	352
4E3	4/78	1663	434
4E4	2/79	1736	411*
4E5	2/80	2162	184*

* Problems fixed in field as of August 26, 1980.

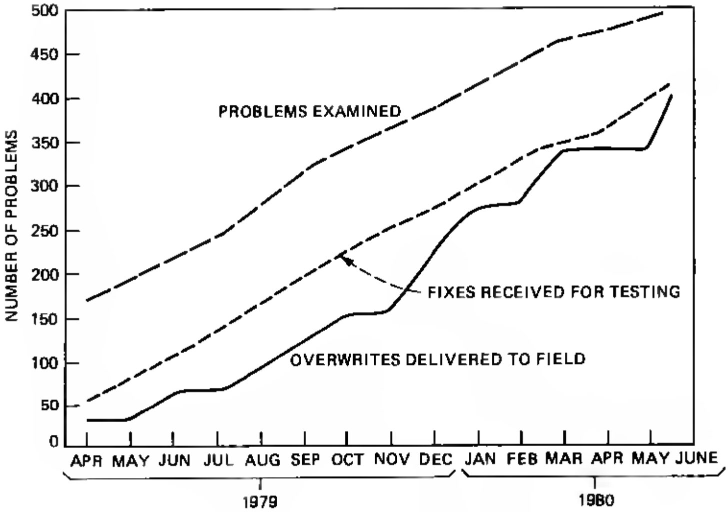

Fig. 5—4E4 generic problem status.

which each No. 4 ESS replaces its current generic program with the latest generic. Current plans call for each office to receive the new generic within a year of its official release. Figure 6 shows the number of retrofits each year since 1976, indicating a large increase as new offices have been added.

A new office data base is compiled for each retrofit. The data base is expanded in anticipation of future growth and also includes a recompiled description of the current office data. Other types of

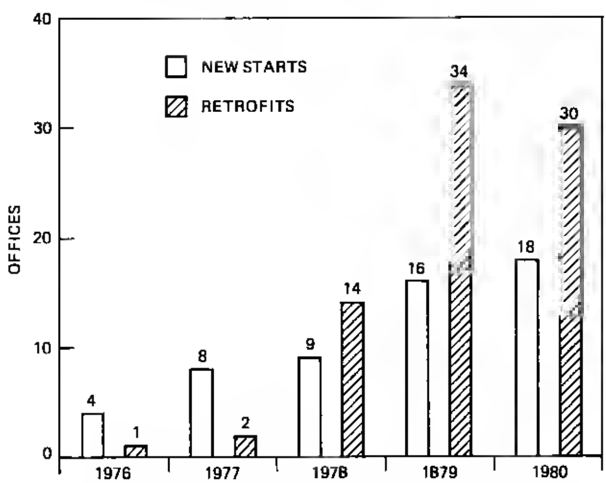

Fig. 6—Trend in No. 4 ESS retrofit activity.

software changes generally made during retrofits, and also once between them (as "midgeneric releases"), are the introduction of new network management software, new trouble-locating procedure tapes that help office maintenance personnel locate faulty circuit packs when diagnostic tests indicate trouble, and new library programs that contain infrequently used test and administrative programs.

4.7 Rearrangements

In addition to hardware changes, software changes, growth and retrofit activity, office performance can also be affected by major rearrangements. Three principal kinds of rearrangements have occurred. Common-Channel Interoffice Signaling terminals in the first 28 offices are being rearranged to improve system reliability. This involved growth of new terminals and execution of a special library program to modify 12 translators in the office data base to effect a new terminal pairing arrangement. The second major rearrangement was a series of activities to allow one office to serve as a gateway office, a function normally planned when an office is first installed. The third type of rearrangement performed was to change the pulse point control for large numbers of frames in one office to increase its reliability.

4.8 Repair

Equipment fails and requires repair on an ongoing basis in No. 4 ESS offices. The average circuit-pack replacement rate for the first quarter of 1980 was 1.7 per day per office. This is half the rate experienced during the first 122 days of Chicago 7 operation in 1976, and it meets the short-term objective of less than two per day per office.[1] To place this number in perspective, a typical No. 4 ESS contains 50,000 circuit packs. In a small fraction of cases, office technicians must use oscilloscopes and probe communication buses and backplane wiring to isolate equipment faults. Such routine repair of equipment often involves several steps, and human error in performing them accounts for 18 percent of the service-affecting incidents.

4.9 Other factors

Although No. 4 ESS offices are well-protected from most external factors, some have had an impact on service. In particular, some offices have been affected by air-conditioning problems, power-distribution failures, failure of non-No. 4 ESS equipment, and static discharge.

V. SERVICE EXPERIENCE

5.1 Service-affecting incidents

To track the performance of No. 4 ESS, the notion of a service-affecting incident (or simply, incident) has been defined as those

equipment failures and major system recovery actions with a significant effect on the customer. Specifically, they include:

(*i*) Hardware failures affecting more than 360 trunks.

(*ii*) System recovery directed Phase 1 and Phases 2, 3, and 4.

(*iii*) System reinitializations.

5.1.1 Hardware failures

Hardware failures affecting more than 360 trunks are called Multiple Unit Failures (MUFs). Originally, MUFs represented half the trunks served by a Voiceband Interface Frame (VIF). With the addition of frames, such as the DIF serving up to 3840 trunks, a MUF is now defined as an outage affecting more than 360 trunks. In duplicated equipment, duplex failures and/or restoral from them, also cause the recovery actions described in Section 5.1.2.

5.1.2 System recovery

When the No. 4 ESS must halt call processing to recover from problems, the result is called a system recovery phase. In a directed Phase 1, all calls associated with a duplex-failed peripheral frame are lost; however, the other stable calls in the system are saved. A directed Phase 1 can have a duration from 1 to 15 seconds.

A Phase 2 is used to recover from memory mutilation or peripheral configuration problems. It checks the integrity of fixed data, such as program store with a hashing algorithm, reconfigures the peripheral complex with peripheral bootstrap (when F-level interrupts implicate the periphery), and initializes most of the call store memory spectrum that is not related to stable calls. A Phase 2 saves stable calls and requires less than 30 seconds if peripheral recovery is not required, and less than 60 seconds if it is. Calls in the dialing state are lost during a Phase 2.

A Phase 3 is used when a complete processor or peripheral reconfiguration is required. It lasts from 1 to 4 minutes, depending on office size, and saves stable calls. Calls in the dialing state are lost, as in a Phase 2.

A Phase 4 is similar to a Phase 3, but it is initiated manually and disconnects all calls.

5.1.3 System reinitialization

A System Reinitialization is a complete reload of the generic program from magnetic tape. It is required only under the most severe cases in which data in program store and both file stores are mutilated. It can take up to 20 minutes and it disconnects all calls.

5.1.4 Number of incidents

When several recovery phases or MUFs are stimulated by the same

event, or follow in succession, they are considered a single incident. All No. 4 ESS service-affecting incidents are recorded and analyzed. The record of these incidents provides an extremely valuable method for evaluating system performance and for guiding efforts to improve it.

Figure 7 is a graph of the number of service-affecting incidents per office per month. The trend indicated is a reduction in the average number experienced by an office to 1.4 per month during the first quarter of 1980. It is significant that a high fraction of service-affecting incidents occur in low traffic periods. Over 55 percent of the "no call processing" time (see Section 5.3.1) has occurred between midnight and 8:00 a.m. to a great extent because routine exercise, complicated repairs, change installation, growth activity, retrofits, and other activities with high risk are generally scheduled during the periods of lowest traffic.

Each service-affecting incident is classified into one or more of the categories shown in Fig. 8. Software design problems account for 25 percent of the total causes. These problems form the basis of an investigation list that is used to guide software current engineering effort. The expected category comprises 16 percent of the incidents. These are cases in which the system reacted as expected, such as planned retrofits, intentional test phases, or when it is impossible to resolve a problem to the proper unit of a duplicated pair and the system must randomly choose the unit to be removed. Duplex frame failures are incidents that occur because a frame is simplex for repair and a fault develops in the active controller. They comprise 11 percent of the total. Unresolved incidents are 13 percent for which sufficient

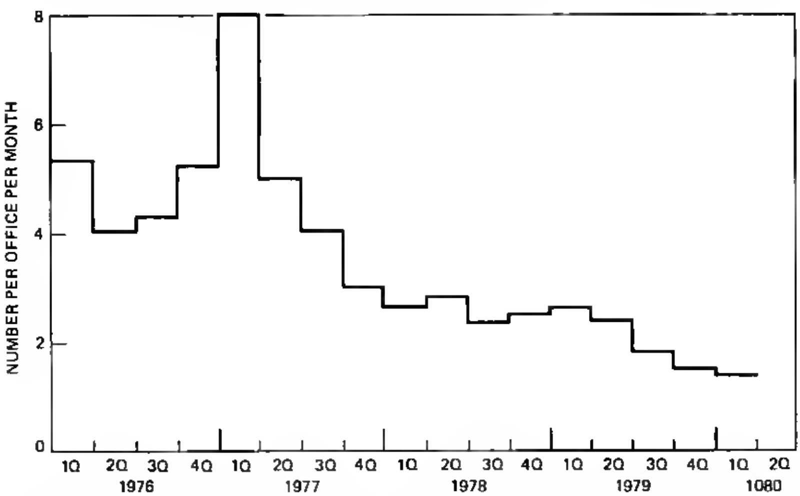

Fig. 7—Service-affecting incidents. The average for the first quarter of 1980 was 1.4 incidents per office per month.

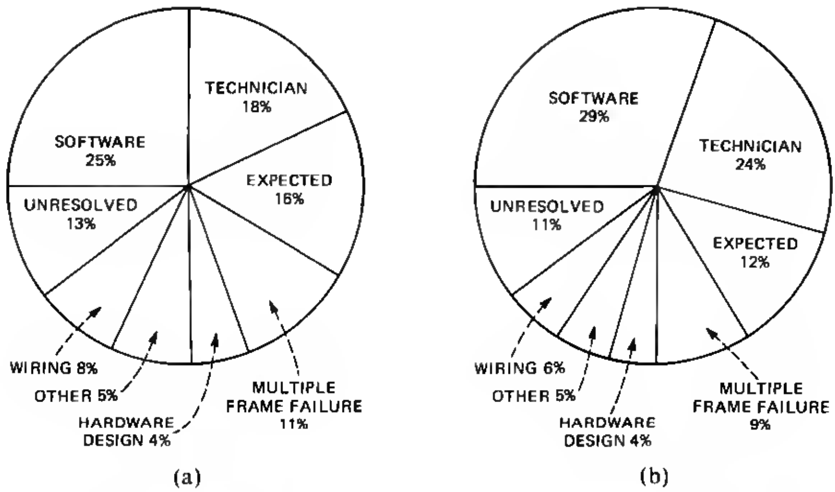

Fig. 8—Causes of service-affecting incidents, cumulative through March 31, 1980. (a) Percent of incidents. (b) Percent of no call processing time.

data to thoroughly analyze the source of the incident is unavailable. Hardware design incidents are the 4 percent caused hy the hardware design of a particular frame or suhunit. Hardware design problems are considered hy the No. 4 ESS hardware change committee and fixes are scheduled as appropriate. Wiring errors account for 8 percent of the incidents and include wiring hreaks or loss of insulation integrity as well as errors or wire clippings inadvertently left in equipment when it was being repaired or modified. The technician error category includes operating telephone company craft and Western Electric installer errors, and comprise 18 percent of the total. Figure 8 also shows the causes for service-affecting incidents hy their contribution to system no call processing time.

5.2 Customer Impact

The principal No. 4 ESS performance measures are those that show the impact of service-affecting incidents on the customer: cutoff calls and denied calls.

Figure 9 shows the rate of calls cutoff by the No. 4 ESS. The first quarter, 1980, rate was 0.18 per 10,000 calls, well helow the ohjective of 1.25 per 10,000. Denied calls are the measure of the No. 4 ESS contrihution to the customer's ahility to complete calls on demand due to no call processing time. During the first quarter, 1980, the rate of denied calls was 0.28 per 10,000. The trend in the number of calls denied by the No. 4 ESS is shown in Fig. 10. The effect on the customer of denied calls is difficult to measure, since alternate routing strategies

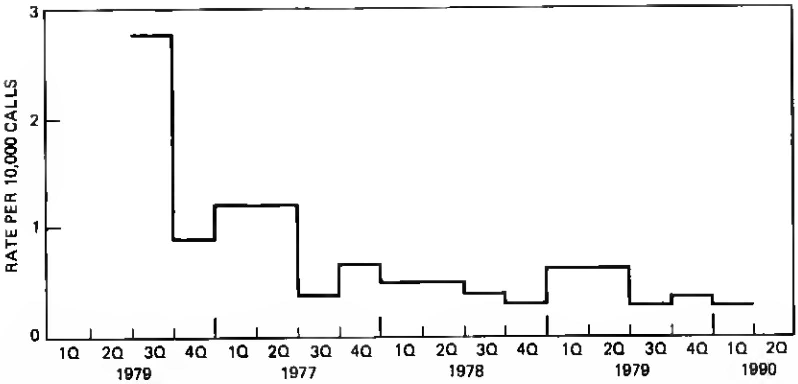

Fig. 9—Cutoff calls. The first quarter 1980 rate was 0.18 per 10,000 calls, well below the objective, which was 1.25 per 10,000 calls.

elsewhere in the network can compensate for some No. 4 ESS denied calls, often allowing the customer to complete the intended call. Both measures show substantial improvement over the period of time the No. 4 ESS has been deployed.

5.3 System performance

In addition to cutoff and denied calls, other performance factors are

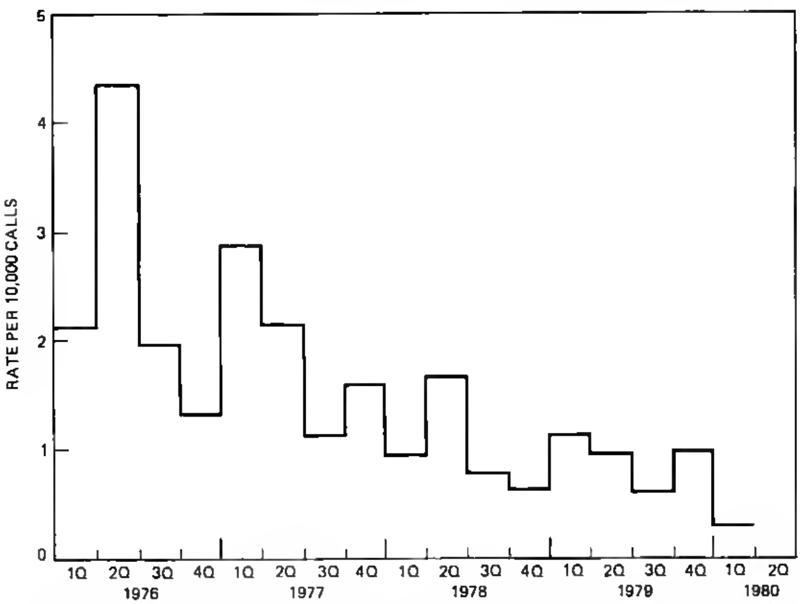

Fig. 10—Denied calls. In the first quarter of 1980, the rate of denied calls was 0.28 per 10,000 calls.

also used to give a more comprehensive measure of system performance. They are system- rather than customer-related measures of system performance and include:

(*i*) no call processing time,
(*ii*) trunk outage time, and
(*iii*) Ineffective Machine Attempts (IMA).

5.3.1 "No call processing" time

No call processing time is often expressed in terms of hours of time in 40 years. It includes outage time required for system reinitialization such as Phases 2, 3, and 4 and directed Phase 1 recovery actions. Note that during the No. 4 ESS no call processing time caused by Phase 2 and Phase 3, all stable calls continue, unless there is also a duplex failure of network or network interface equipment. Figure 11 illustrates that the long-term trend has been an improvement in "no call processing" time to a first quarter, 1980, rate of 9.9 hours in 40 years. Since generic retrofits and data base updates require use of an intentional Phase 3 during the lowest traffic periods, there is a built-in requirement that approximately 1 hour in 40 years of this total be used for this purpose. Customer impact is minimal because network management controls applied as part of the retrofit procedure virtually eliminate any customer impact. The rate of 9.9 hours in 40 years is comprised of

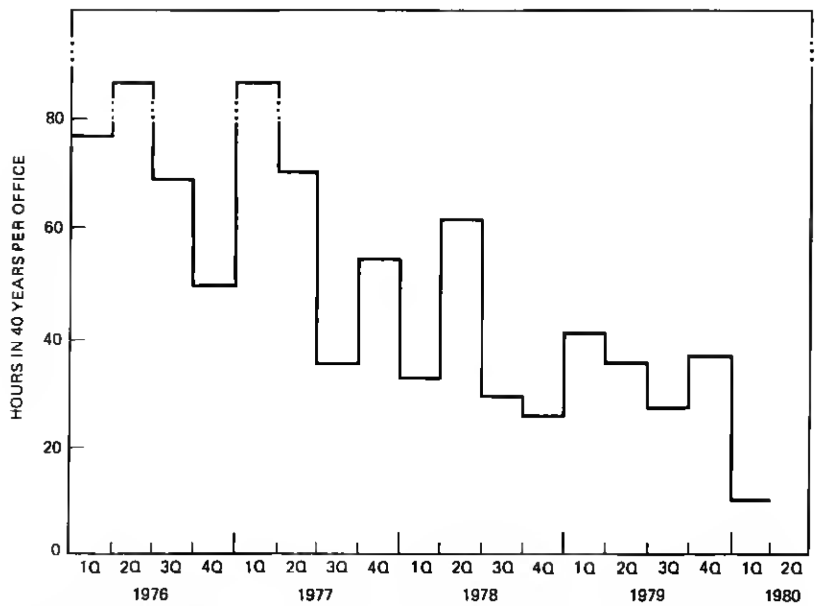

Fig. 11—No call processing. The first-quarter 1980 rate was 9.9 hours in 40 years. The objective was 2.0 hours in 40 years.

all of the factors shown in Figure 8. It is significant that factors, such as procedural errors and software deficiencies, that could not be specifically modeled (see Section III), account for nearly two-thirds of all downtime. Consequently, the internal objective of 2 hours in 40 years of total system unavailability is under review. Nevertheless, no call processing time has steadily improved as maintenance and reliability enhancements have been added to the system.

Figure 12 shows the effect of two recent enhancements. It presents overlapping histograms showing the distribution of no call processing incidents for two 6-month periods, one ending on March 31, 1979, and another ending 1 year later. The significance of the first histogram is that is represents No. 4 ESS performance before the directed Phase 1 feature was available. The directed Phase 1 was introduced in the 4E4 generic program and has been deployed both in new offices and through generic program retrofits. By Marcb 31, 1980, all offices had the directed Phase 1 feature. Normally, the directed Phase 1 takes about 2 seconds to initialize a duplex-failed TSI frame. Prior to the directed Phase 1, a 1- to 3-minute Phase 3 was required. The significance of the second histogram is that the directed Phase 1 shifted the distribution so that 34 percent of all no call processing incidents require less than 30 seconds as compared with 2 percent prior to directed Phase 1. An additional enhancement, introduced late in 1979, was a shortened Phase 2 when no peripheral equipment was suspected by system integrity programs. This also reduces the no call processing time.

5.3.2 Trunk outage time

Trunk outage time is the measure of hardware failures, such as duplex-failed equipment or MUFS. Note that no call processing time is not included in trunk outage time measurements. Figure 13 shows a graph of No. 4 ESS trunk outage time. During the first quarter of 1980, the system performance was 38.0 minutes of outage per trunk per year compared with an objective of 28.0. Several maintenance enhancements are planned to help bring No. 4 ESS performance closer to this objective.

5.3.3 Ineffective machine attempts

Some customer attempts to originate calls result in noncompleted calls. The No. 4 ESS has a large and precise ineffective-attempt reporting system that measures call failure statistics and allows an analysis of chronic problems. Over 300 call-failure modes are defined, including customer errors, failure of switching machines or transmission media connected in an incoming mode to the No. 4 ESS, failure of the No. 4 ESS to establish a cross-office connection, and a failure of the switching

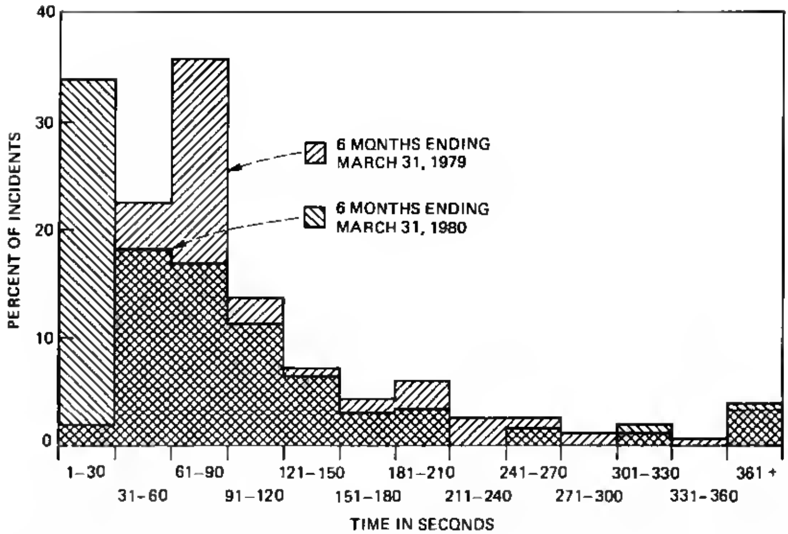

Fig. 12—Incident duration for two six-month intervals that show the impact of the directed Phase 1 and shortened Phase 2.

machine or transmission media connected in an outgoing mode to the No. 4 ESS. A subset of the total ineffective attempts is classified as an IMA. These include calls that must be terminated with incoming, connecting or outgoing reorder tone, vacant code announcements, or no-circuit tone.

Figure 14 shows that the average adjusted domestic IMA performance has remained relatively constant at a little over 1 percent of all attempts. The rate during the first quarter of 1980 was 1.02 percent,

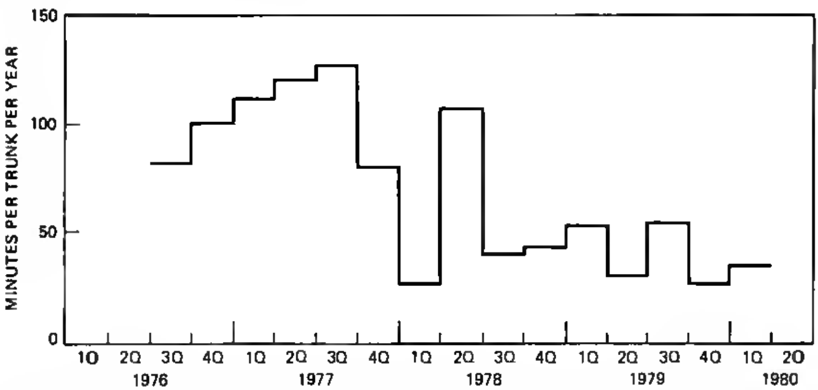

Fig. 13—Trunk minutes out of service. For the first quarter of 1980 the system performance was 38.0 minutes of outage per trunk per year. The objective was 28.0.

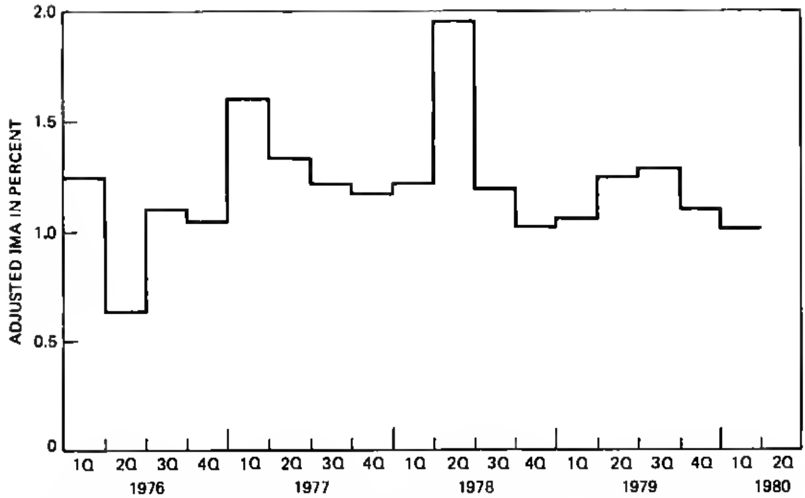

Fig. 14—Ineffective machine attempts. The first quarter of 1980 had a rate of 1.02 percent. The original objective was 1.25 percent.

meeting the original objective of 1.25 percent. The rate for calls to other countries is higher. A study of the specific failures shows that the No. 4 ESS and outgoing trunks contribute to less than 0.01 percent of the total number of IMAs. Most failures originate from irregularities in the incoming network. Further analysis shows that in large metropolitan systems, such as those in Chicago and New York City where common control Class 5 offices with multifrequency signaling or CCIS are used, the reorder component of IMA for domestic calls ranges between only 0.2 to 0.3 percent. However, where step-by-step or early vintage crossbar switches are used, the reorder IMA ranges between 2 and 3 percent even though the equipment is properly maintained. This can frequently be attributed largely to outside plant problems not screened by these systems. The IMA data are effective in identifying network problems, and also serve as a continuous check on network performance.

5.4 Interrupts

One of the most closely watched system maintenance indicators in No. 4 ESS is the level of system interrupts. They generally indicate an unexpected response from a system action. For example, an equipment failure that affects a path through the time-division network may cause interrupts. (For a more complete description of system interrupts, see Refs. 2 and 5.)

Although interrupts do not directly affect the customer, an objective has been set to help manage system maintenance activity. When the

interrupt level rises, more attention needs to be spent on maintenance. The original empirical interrupt objective of less than 50 per day has been tigbtened to an average of less than 40 per day. Some small offices have an objective that is more stringent since they have less equipment. The average number of interrupts per office during the first quarter of 1980 was less than 25 per day, meeting the objective.

VI. MANAGING PERFORMANCE

6.1 Ongoing development

The original design and implementation of the No. 4 ESS are key factors in allowing the system to provide the current level of service. However, another key ingredient has been the management of No. 4 ESS performance.

Each service-affecting incident is recorded in a data base and analysis is performed monthly to track the overall performance. When analysis has shown that specific improvements can belp improve system performance, they become candidates for features to be developed as part of the next generic program release. Committees review each new feature candidate for its impact on system resources, the development effort required, and the feature's value relative to other candidates. The directed Phase 1 was such a feature; it was proposed when analysis showed it could reduce system no call processing time.

6.2 Current engineering

In addition to new features aimed at improving performance, an ongoing effort also exists to identify problems in existing systems and to deliver fixes. Specific responsibility for carrying out this effort is assigned to a group that works closely with developers to generate the necessary fixes. Much of this effort is directed toward the large generic program. However, with the rapid introduction of new equipment, all modifications to existing hardware designs are also tracked by the hardware change committee.

6.3 Acceptance tests

In addition to its basic design, No. 4 ESS performance is affected by how well each new system is installed and how in-service systems are operated. New systems must meet rigorous operational readiness tests and final verification acceptance tests before they are turned over from the installer to the operating telephone company (OTC). Before the OTC places the system in service, it must meet another set of performance criteria, of which the 7-day sliding interrupt average is the most visible. These performance criteria are specified in Bell System Practices and Western Electric Installation Handbooks expressly to help the OTCs manage the quality of initial service they offer. After initial service,

extensive service results performance measurements or indices are used to help judge the effectiveness of the team operating each No. 4 ESS.

6.4 Managing deployment

Besides the performance of each individual No. 4 ESS, performance management has been extended to help govern the rate at which new systems are deployed with new software and hardware. Specific recommendations have been published in cooperation with AT&T that establish intervals after the first application office for subsequent new offices and for the beginning of the generic retrofit program. These recommendations limit the initial exposure of new software and hardware until sufficient experience is gained under actual operating conditions to allow rapid deployment with confidence that service performance standards will be maintained.

The recommendations also specify the composition and duties of steering and cutover committees for each new system and major growth job. Recent experience indicates that these committees can be very effective and are key ingredients in the smooth transition from an earlier system to a new No. 4 ESS.

As indicated in Section III, there are many demands for changes, rearrangements, and additions to existing systems. To help manage this high level of activity, as well as arbitrating schedule conflicts for new systems, retrofits, and data base updates, an Implementation Review Committee was formed with representatives knowledgeable in OTC needs, Western Electric production and installation capacities, and Bell Labs development capabilities and schedules. One of its tasks is to help manage peak demands, such as the high fraction of systems requesting spring service dates to help meet busy season traffic demands.

VII. SUMMARY

The No. 4 ESS has been incorporated successfully into the Bell System and international telecommunications network. Since the cutover of the first system in Chicago in January 1976, 51 systems terminating over 1,000,000 trunks have been put into service. During this period, the hardware and software have evolved to include the latest technology which has made possible additional equipment cost savings and a reduction in space and power requirements.

Experience with the No. 4 ESS has confirmed the original design criteria for improved reliability and maintainability in stored programmed control systems as follows:

(*i*) Reliability, maintainability, and administrative features must be included in the original architecture of the entire system.

(*ii*) Software integrity features are necessary to allow large systems to perform successfully in an environment containing software problems.

(*iii*) Automatic and semiautomatic maintenance aids are mandatory for maintaining modern systems.

(*iv*) Many factors other than component failures cause reliability problems and must be considered in basic design decisions.

(*v*) Built-in facilities for continually measuring performance parameters are needed to make sure that performance criteria are met and to identify where improvements are required.

(*vi*) Performance criteria should be based on customer impact.

Inclusion of these concepts in the No. 4 ESS has been a major factor in its excellent performance and rapid deployment.

VIII. ACKNOWLEDGMENTS

Many of the performance statistics presented in this article were compiled by K. J. Rice. The authors would especially like to thank her for this contribution. Also, the steadily improving performance trends are attributed to the dedicated effort by No. 4 ESS designers, the diligence of the people operating No. 4 ESS systems, and the excellent support they receive from the SMCCs, the No. 4 ESS National Electronic Switching Assistance Center, and the Western Electric PECC.

REFERENCES

1. H. B. Compton et al., "System Integration and Early Office Planning," B.S.T.J., *56*, No. 7 (September 1977), pp. 1279–96.
2. J. J. Kulzer, "Systems Reliability—A Case Study of No. 4 ESS," INFOTECH State of the Art Conference on Computer System Reliability, London, England, June 1977.
3. P. K. Giloth and J. A. Giunta, "No. 4 ESS Operations and Performance," Int. Switching Symp., Paris, France, May 1979, pp. 1071–8.
4. E. A. Davis, "No. 4 ESS Growth: Serving Increased Toll Switching Needs," Bell Labs Record, *58*, No. 5 (May 1980), pp. 146–51.
5. M. N. Meyers, W. A. Routt, and K. W. Yoder, "Maintenance Software," B.S.T.J., *56*, No. 7 (September 1977), pp. 1139–67.
6. P. K. Giloth and H. E. Vaughan, "Early No. 4 ESS Field Experience," Int. Switching Symp., Kyoto, Japan, October 1976.
7. R. A. Bruce, P. K. Giloth, and E. H. Siegel, Jr., "No. 4 ESS—Evolution of a Digital Switching System," IEEE Trans. Commun., *COM-27*, No. 7 (July 1979), pp. 1001–11.
8. P. K. Gilotb, "No. 4 ESS Reliability and Maintainability Experience," 1980 Proc. Annu. Reliability and Maintainability Symp, pp. 388–392.